a distance along the optical axis between those two optical elements, an annular ratio of the secondary light source formed on the exit plane of the fly-eye lens can be changed.

Further, in the embodiment shown in FIG. 11, design may be made such that the inner diameter and outer diameter of the aperture stop 6 are variable, and this aperture stop 6 may be disposed at any location which is conjugate with the position at which the secondary light source is formed. For example, it is also conceivable to dispose a stop of which the diameter of the opening portion is variable on the exit surface side of the fly-eye lens 5, dispose a stop of which the diameter of the light intercepting portion is variable at a location conjugate with the exit surface of the fly-eye lens, and vary the annular ratio and σ value of the annular secondary light source.

In the above described embodiments, the aperture stop may be formed by a transparent type liquid crystal display device, an electrochromic device or the like.

What is claimed is:

1. A projection exposure apparatus including:

illuminating optical means for illuminating a projection negative; and

projection optical means for projection-exposing said projection negative illuminated by said illuminating optical means onto a substrate;

said illuminating optical means including light source means for supplying exposure light, annular light source forming means for forming an annular secondary light source, which has a plurality of light source images, by the light from said light source means, and condenser means for condensing light from said annular light source forming means on said projection negative;

said apparatus satisfying the following condition:

$$1/3 \leqq d_1/d_2 \leqq 2/3,$$

where $d_1$ is the inner diameter of said annular secondary light source, and $d_2$ is the outer diameter of said annular secondary light source;

said apparatus also satisfying the following condition:

$$0.45 \leqq NA_2/NA_1 \leqq 0.8,$$

where $NA_1$ is the numerical aperture of said projection optical means, and $NA_2$ is the numerical aperture of said illuminating optical means determined by the outer diameter of said annular secondary light source.

2. A projection exposure apparatus according to claim 1, wherein said annular light source forming means includes:

an optical integrator; and

stop means disposed in the optical path of light emerging from said optical integrator and having an annular opening portion.

3. A projection exposure apparatus according to claim 2, wherein said optical integrator is comprised of a plurality of lens elements.

4. A projection exposure apparatus according to claim 2, wherein said optical integrator includes a bar-like optical element.

5. A projection exposure apparatus according to claim 2, wherein said stop means has a plurality of opening portions differing in the ratio of the inner diameter of said annular opening portion to the outer diameter of said annular opening portion from one another, and one of said plurality of opening portions of said stop means is disposed in said optical path.

6. A projection exposure apparatus according to claim 5, wherein said stop means includes a circular opening portion.

7. A projection exposure apparatus according to claim 5, further including:

driving means for disposing one of said plurality of opening portions in said optical path;

input means for inputting information regarding various conditions during exposure; and

control means for controlling said driving means on the basis of the input information from said input means.

8. A projection exposure apparatus according to claim 7, wherein said input means includes detecting means for detecting a mark on said projection negative on which the information regarding the various conditions during exposure is recorded.

9. A projection exposure apparatus according to claim 1, wherein said projection optical means includes an aperture stop of which the diameter of the opening is variable, and said projection exposure apparatus further includes:

driving means for varying said diameter of the opening of said aperture stop;

input means for inputting information regarding various conditions during exposure; and

control means for controlling said driving means on the basis of the input information from said input means.

10. A projection exposure apparatus according to claim 1, wherein said annular light source forming means includes light guide means for transmitting said exposure light.

11. A projection exposure apparatus according to claim 10, wherein said light guide means is constructed such that the entrance side cross-sectional shape of said light guide means is circular and the exit side cross-sectional shape of said light guide means is annular.

12. A projection exposure apparatus including:

illumination optical means for illuminating a projection negative; and

projection optical means for projection-exposing said projection negative illuminated by said illumination optical means onto a substrate;

said illumination optical means including light source means for supplying exposure light, means for forming a secondary light source, which has a plurality of light source images, by the light from said light source means, means including annular ratio changing means for converting said secondary light source into an annular secondary light source and changing a ratio between an inner diameter and outer diameter of said annular secondary light source, and condenser means for condensing light from said annular secondary light source onto said projection negative,

said apparatus satisfying the following condition:

$$\frac{1}{3} \leqq d_1/d_2 \leqq \frac{2}{3}$$

where $d_1$ is the inner diameter of said annular secondary light source, and $d_2$ is the outer diameter of said annular secondary light source, and said apparatus satisfying the following condition:

$$0.45 \leqq NA_2/NA_1 \leqq 0.8$$

where $NA_1$ is the numerical aperture of said projection optical means, and $NA_2$ is the numerical aperture of said illumination optical means determined by the outer diameter of said annular secondary light source.

13. A projection exposure apparatus according to claim 12, wherein said means for forming said secondary light source has an optical integrator.

14. A projection exposure apparatus according to claim 13, wherein said annular ratio changing means includes stop means disposed in an optical path of light flux emergent from said optical integrator and having an annular opening portion.

15. A projection exposure apparatus according to claim 14, wherein said stop means includes a plurality of opening portions differing from one another in a ratio of inner diameter of said annular opening portion to outer diameter of said annular opening portion, and one of said plurality of opening portions of said stop means is disposed in the optical path of said illumination optical means.

16. A projection exposure apparatus according to claim 15, wherein said stop means includes a circular opening portion.

17. A projection exposure apparatus according to claim 15, further including:

driving means for disposing one of said plurality of opening portions in said optical path;

input means for inputting information regarding various conditions during exposure; and

control means for controlling said driving means on the basis of the input information from said input means.

18. A projection exposure apparatus according to claim 12, further including:

input means for inputting information regarding various conditions during exposure; and

control means for controlling said annular ratio changing means on the basis of the input information from said input means.

19. A projection exposure apparatus according to claim 18, wherein said annular ratio changing means includes a plurality of opening portions of which a ratio between an inner diameter and an outer diameter is different from one another, and one of said plurality of opening portions is disposed in an optical path of said illumination optical means.

20. A projection exposure apparatus according to claim 18, wherein said annular ratio changing means is disposed in an optical path of said illumination optical means and includes a movable stop for changing the ratio between the inner diameter and outer diameter.

21. A projection exposure apparatus comprising: an illuminating optical system; and

a projection optical system;

said illumination optical system including a light source, an optical integrator and a condenser optical system;

light from said light source passing through said optical integrator, said condenser optical system, a projection negative and said projection optical system, and onto a substrate;

said optical integrator forming a plurality of annular light source images; and

the following conditions being satisfied:

$$\frac{1}{3} \leqq d_1/d_2 \leqq \frac{2}{3}$$

$$0.45 \leqq NA_2/NA_1 \leqq 0.8$$

where $d_1$ is an inner diameter of said plurality of annular light source images, $d_2$ is an outer diameter of said plurality of annular light source images, $NA_1$ is the numerical aperture of said projection optical system at a side of said projection negative and $NA_2$ is the numerical aperture of said condenser optical system at

an exit side determined by the outer diameter of said plurality of annular light source images.

22. A projection exposure apparatus including:

an illumination optical system; and

a projection optical system;

said illumination optical system including a light source, an optical integrator, an annular stop and a condenser optical system;

light from said light source passing through said optical integrator, said condenser optical system, a projection negative and said projection optical system and onto a substrate;

said annular stop being provided at a position where a plurality of images are formed by said illumination optical system;

said apparatus satisfying the following conditions:

$$\tfrac{1}{3} \leqq d_1/d_2 \leqq \tfrac{2}{3}$$

$$0.45 \leqq NA_2/NA_1 \leqq 0.8$$

where $d_1$ is an inner diameter of an opening of said annular stop, $d_2$ is an outer diameter of the opening of said annular stop, $NA_1$ is the numerical aperture of said projection optical system at a side of said projection negative and $NA_2$ is the numerical aperture of said condenser optical system at an exit side determined by the outer diameter of the opening of said annular stop.

23. A projection exposure apparatus comprising:

an illuminating optical system; and

a projection optical system;

said illuminating optical system including a light source, an optical integrator, an annular stop and a condenser optical system;

light from said light source passing through said optical integrator, said condenser optical system, a projection negative and said projection optical system and onto a substrate;

said illuminating optical system forming a plurality of annular light source images satisfying the following condition:

$$\tfrac{1}{3} \leqq d_1/d_2 \leqq \tfrac{2}{3}$$

where $d_1$ is an inner diameter of said plurality of annular light source images and $d_2$ is an outer diameter of said plurality of annular light source images; and

said projection exposure apparatus satisfying the following condition:

$$0.45 \leqq NA_2/NA_1 \leqq 0.8,$$

where $NA_1$ is the numerical aperture of said projection optical system at a side of said projection negative, and $NA_2$ is the numerical aperture of said condenser optical system at an exit side determined by an outer diameter of an opening of said annular stop.

24. A projection exposure apparatus comprising:

an illuminating optical system; and

a projection optical system;

said illuminating optical system including a light source, an optical integrator and a condenser optical system;

light from said light source passing through said optical integrator, said condenser optical system, a projection negative and said projection optical system and onto a substrate;

said illuminating optical system forming a plurality of annular light source images satisfying the following condition:

$$\frac{1}{3} \leqq d_1/d_2 \leqq \frac{2}{3},$$

where $d_1$ is an inner diameter of said plurality of annular light source images, $d_2$ is an outer diameter of said plurality of annular light source images;

the ratio between the inner diameter and the outer diameter of said annular light source images being variable within the range of said condition;

said projection exposure apparatus satisfying the following condition:

$$0.45 \leqq NA_2/NA_1 \leqq 0.8,$$

where $NA_1$ is the numerical aperture of said projection optical system at a side of said projection negative, and $NA_2$ is the numerical aperture of said condenser optical system at an exit side determined by the outer diameter of said plurality of annular light source images.

25. A projection exposure apparatus comprising:

an illuminating optical system; and

a projection optical system;

said illuminating optical system including a light source, an optical integrator, a first annular stop, a second annular stop and a condenser optical system;

light from said light source passing through said optical integrator, said condenser optical system, a projection negative and said projection optical system and onto a substrate;

said first and second annular stops satisfying the following condition:

$$\frac{1}{3} \leqq d_1/d_2 \leqq \frac{2}{3},$$

where $d_1$ is an inner diameter of an opening of said annular stops and $d_2$ is an outer diameter of an opening of said annular stops;

said first and second annular stops being selectively disposed in a position where a plurality of light source images are formed by said illuminating optical system; and

said projection exposure apparatus satisfying the following condition:

$$0.45 \leqq NA_2/NA_1 \leqq 0.8,$$

where $NA_1$ is the numerical aperture of said projection optical system at a side of said projection negative, and $NA_2$ is the numerical aperture of said condenser optical system at an exit side determined by the outer diameter of said plurality of annular light source images.

* * * * *

26. A projection exposure apparatus comprising:

an illumination optical system including an optical integrator that forms a substantially annular secondary light source; and

a projection optical system,

said illumination optical system satisfying the following condition:

$$1/3 \le d_1/d_2 \le 2/3$$

wherein $d_1$ is an inner diameter of the secondary light source and $d_2$ is an outer diameter of the secondary light source.

27. A projection exposure apparatus comprising:

an illumination optical system including an optical integrator through which a light beam irradiated on a mask passes; and

a projection optical system;

said illumination optical system providing an intensity distribution of the light beam with an annular increased intensity portion relative to the inside thereof, and

said illumination optical system satisfying the following condition:

$$0.45 \le NA_2/NA_1 \le 0.8$$

wherein $NA_1$ is the numerical aperture of said projection optical system, and $NA_2$ is the numerical aperture of light from the increased intensity portion.

28. A projection exposure apparatus comprising:

an illumination optical system including an optical integrator through which a light beam irradiated on a mask passes; and

a projection optical system;

said illumination optical system providing an intensity distribution of the light beam with an annular increased intensity portion relative to the inside thereof and changing the intensity distribution in accordance with a pattern formed on the mask so as to maintain a shape of the annular increased intensity portion.

29. A projection exposure apparatus comprising:

an illumination optical system disposed between a light source and a mask;

a projection optical system disposed between the mask and a substrate; and

an optical device, disposed within the illumination optical system, that forms a plurality of secondary light sources including a substantially annular secondary light source and a substantially circular secondary light source with light from the light source to illuminate the mask with light from one of the plurality of secondary light sources, the optical device changing an intensity distribution of the annular secondary light source so as not to change the shape thereof and changing an intensity distribution of the

circular secondary light source so as not to change the shape thereof.

30. A combination of an illuminator and a photolithographic projection imager, the combination comprising:

a. an illuminator optical system for directing illumination from a source to a pupil of the illuminator from which a reticle is illuminated to be imaged on a wafer by an objective imaging system;

b. the illuminator in a collimated region of illumination upstream of the illuminator pupil having a pair of refractive elements having conical surfaces that are respectively concave and convex;

c. said elements being arranged so that an upstream one of said elements diverges the illumination into a single beam having an annular configuration of intensity and a downstream one of said elements counters the divergence caused by the upstream element to give the illumination an annular intensity profile of the single beam at the pupil of the illuminator; and

d. a uniformizer arranged between said elements and the pupil of the illuminator.

31. The combination of Claim 30, wherein the distance between said elements is variable to vary the radius of said annular intensity profile.

32. The combination of Claim 31, wherein said distance between said elements can be reduced enough to counter said

divergence approximately at its source to keep said intensity configuration from becoming annular.

33. The combination of Claim 30, wherein said upstream element has said concave conical surface and said downstream element has said convex conical surface.

34. The combination of Claim 30, wherein a mask is positionable at said pupil within said annular intensity profile.

35. The combination of Claim 30, wherein said concave and convex conical surfaces have the same conic angle.

36. The combination of Claim 30, wherein said elements are separated by an air gap.

37. The combination of Claim 30, wherein said conical surfaces are arranged to confront each other.

38. The combination of Claim 37, wherein the distance between said elements is variable to vary the radius of said annular intensity profile to accommodate characteristics of the reticle.

39. The combination of Claim 38, wherein said conical surfaces can be moved into proximity for countering said

divergence to keep said intensity configuration from becoming annular.

40. The combination of Claim 39, wherein a mask of variable size is positionable downstream of said conical surfaces within said annular intensity profile.

41. The combination of Claim 30, wherein said refractive elements are faceted.

42. In an illuminator for a photolithographic projection imager, the improvement comprising:

a. a first refractive element arranged in a collimated region of an illumination path of said illuminator upstream of a pupil of said illuminator so that a conical surface of said first refractive element diverges the illumination into a single beam having an annular configuration of intensity;

b. a second refractive element arranged to receive diverged illumination from said first refractive element and said second refractive element having a conical surface arranged for countering the illumination divergence caused by said first refractive element to fix the radius of the divergence of the single beam of said illumination;

c. the radius of divergence of the illumination output from the second refractive element appearing as an annular intensity profile of illumination at the pupil region of the illuminator causing illumination with an annular intensity

profile to illuminate a reticle that is imaged onto a wafer by an objective imaging system of the photolithographic projection imager; and

d. a uniformizer arranged between said first and second refractive elements and the pupil of the illuminator.

43. The improvement of Claim 42, wherein said conical surface of said first refractive element is concave, and said conical surface of said second refractive element is convex.

44. The improvement of Claim 42, wherein said first and second refractive elements are separated by an air gap.

45. The improvement of Claim 42, wherein a distance between said refractive elements is variable for varying said radius of illumination divergence to accommodate characteristics of the reticle.

46. The improvement of Claim 45, wherein a minimum of said variable distance between said refractive elements results in said second element countering the illumination divergence so that the configuration of illumination intensity does not become annular.

47. The improvement of Claim 45, including a variable size mask arranged for blocking illumination within said annular configuration of intensity.

48. The improvement of Claim 42, wherein said conic surfaces of said first and second refractive elements have the same conic angle.

49. The improvement of Claim 42, wherein said conic surface of said first and second refractive elements confront each other.

50. The improvement of Claim 49, wherein a distance between said refractive element is variable for varying said radius of illumination divergence to accommodate characteristics of the reticle.

51. The improvement of Claim 50, wherein said illumination divergence is substantially eliminated by moving said conic surfaces into proximity.

52. The improvement of Claim 50, wherein illumination within said annular configuration of intensity is blocked by a mask.

53. The improvement of Claim 42, wherein said conic surfaces of said first and second refractive elements face away from each other.

54. The improvement of Claim 42, wherein said refractive elements are faceted.

55. An illuminator combined with a photolithographic projection imager, the combination comprising:

a. the illuminator having an optical system for directing illumination along an optical axis of the illuminator upstream of a pupil of the illuminator so that an intensity profile of the illumination as the illuminator pupil is directed to a reticle that is imaged on a wafer by an objective imaging system of the photolithographic projection imager;

b. a diverging element arranged in a collimated region of the illumination path of said illuminator upstream of the illuminator pupil for diverging said illumination into a single beam having an annular configuration of intensity;

c. a counter diverging element arranged in said illumination path at a variable distance from said diverging element for receiving said diverging illumination;

d. said counter diverging element being arranged for countering the divergence of said illumination and fixing the radius of said annular configuration of intensity of the

single beam as a function of the distance between said elements;

e. the annular configuration of illumination intensity output from the counter diverging element appearing as an annular intensity profile of the single beam of the illumination at the illuminator pupil and at the reticle so that the radius of the annular intensity profile accommodates characteristics of the reticle; and

f. a uniformizer arranged between said elements and the pupil of the illuminator.

56. The combination of Claim 55, wherein said elements are refractive and have faceted surfaces.

57. The combination of Claim 55, wherein said elements are concentrically diffractive.

58. The combination of Claim 55, wherein said elements are reflective and have conical surfaces.

59. The combination of Claim 55, wherein said elements are refractive and have conical surfaces.

60. The combination of Claim 59, wherein said conical surfaces are concave on one of said elements and convex on another of said elements.

61. The combination of Claim 60, wherein said concave and convex conical surfaces confront each other.

62. The combination of Claim 61, wherein said counter diverging element can be positioned for countering said diverging illumination so that the illumination intensity profile does not become annular.

63. The combination of Claim 60, wherein said concave and convex conical surfaces face away from each other.

64. The combination of Claim 55, wherein said diverging element is refractive and has a concave conical surface.

65. The combination of Claim 55, wherein said counter diverging element is refractive and has a convex conical surface.

66. The combination of Claim 55, wherein said counter diverging element can be positioned for countering said diverging illumination so that said intensity configuration does not become annular.

67. The combination of Claim 55, including a variable size mask positioned to block illumination within said annular configuration.

--68. An illuminator for a photolithographic projection imager including a variable annular illumination intensity profiler, said profiler comprising a pair of diverging and counter diverging elements arranged in the illumination path of said illuminator so that said diverging element diverges the illumination into an annular configuration of intensity and said counter diverging element counters the divergence caused by said diverging element to give the illumination an annular intensity profile the configuration of which is a function of the distance between the pair of elements.--

--69. An illuminator according to Claim 68, wherein the diverging element is a refractive element having a concave conical surface and the counter diverging element is a refractive element having a convex conical surface.--

--70. An illuminator according to Claim 68, wherein the diverging and counter diverging elements are refractive elements that are faceted.--

--71. An illuminator according to Claim 68, wherein said diverging and counter diverging elements are concentrically diffractive.--

--72. An illuminator according to Claim 68, wherein the diverging and counter diverging elements are reflective and have conical surfaces.--

--73. An illuminator according to Claim 68, wherein the diverging element is a first refractive element arranged in the illumination path of the illumination upstream of a pupil region of said illuminator so that a conical surface of said first refractive element diverges the illumination into an annular configuration of intensity, and said counter diverging element is a second refractive element arranged to receive diverged illumination from said first refractive element, said second refractive element having a conical surface arrangeable for countering the illumination divergence caused by said first refractive element and fixing the radius of the divergence of said illumination.--

--74. An illuminator according to any of Claims 68 to 73, wherein the distance between the diverging and counter diverging elements is variable to vary the radius of the annular intensity profile.--

--75. An illuminator according to any of Claims 68 to 73, wherein the distance between the diverging and counter diverging elements can be reduced enough to counter said divergence approximately at its source to keep the intensity configuration from becoming annular.--

--76. An illuminator according to any of Claims 68-73, wherein the diverging and counter diverging elements are arranged on the optical axis of the illuminator upstream of a pupil region of said illuminator.--

--77. An illuminator according to Claim 76, wherein a mask is positioned at the pupil region within the annular intensity profile.--

--78. An illuminator according to any of Claims 68 to 73, wherein the diverging and counter diverging elements are separated by an air gap.--

--79. An illuminator according to Claim 69 or 73, wherein the concave and convex conical surfaces have the same conic angle.--

--80. An illuminator according to Claim 69 or 73, wherein the conical surfaces are arranged to confront each other.--

--81. An illuminator according to Claim 69 or 73, wherein the conical surfaces can be moved into proximity for countering the divergence to keep the intensity configuration from becoming annular.--

--82. An illuminator according to Claim 69 or 73, wherein a mask of variable size is positioned downstream of said conical surfaces within said annular intensity profile.--

--83. An illuminator according to Claim 73, wherein the conical surface of the first refractive element is concave, and the conical surface of the second refractive element is convex.--

--84. An illuminator according to any of Claims 68-73 or 83, wherein a variable size mask is arranged within the illumination path for blocking illumination within the annular configuration of intensity.--

--85. An illuminator according to Claim 84, wherein said illumination divergence is substantially eliminated by moving said conic surfaces into proximity.--

--86. An illuminator according to any of Claims 68-73, wherein the illumination within said annular configuration of intensity is blocked by a mask.--

--87. An illuminator according to Claim 69 or 73, wherein the conic surfaces of the refractive elements face away from each other.--

--88. An illuminator according to Claim 73, wherein the refractive elements are faceted.--

--89. An illuminator according to Claim 79, wherein the concave and convex conical surfaces face away from each other.--

--90. An illuminator according to Claim 68 or 69, wherein a variable size mask is positioned within said illuminator to block illumination within said annular configuration.--



add C3

Add C5

Add D7